

## EFFECT OF CHILLS ON TRIBOLOGICAL BEHAVIOR OF ALUMINUM-GARNET-CARBON HYBRID COMPOSITES

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### ABSTRACT

*The demand of high quality casting with good performance, light-weight materials is being increased in automotive and aircraft industrial applications to achieve fuel economy. Application of the metallic chills with high volumetric heat capacity is one of the primary method to develop required sound quality casings. In the present research work LM 13 aluminum alloy matrix hybrid composites having 3 to 12wt% of garnet in steps of 3wt% and constant 3wt% of Carbon are developed by using chills to improve directional solidification. Experimental investigations are carried out to study the effect of chilling on microstructure, dry sliding wear and sand abrasion behavior of the composite samples. Copper, steel, iron metallic and silicon carbide nonmetallic chills were used to study the tribological behavior of the samples and compared the same with non-chill cast specimens. ASTM standard specimens taken from chill end of the casting were tested for tribological behavior.*

**KEYWORDS:** Aluminum Hybrid, Copper Chill, Garnet, Sand Abrasion & Wear

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### INTRODUCTION

Metal alloys with two or more reinforcements are known as hybrid metal matrix composites (HMMCs). Aluminum matrix HMMCs with multiple insoluble ceramic reinforcements are widely used in various tribological applications of automotive, defence and aerospace sectors [1]. Owing to its light weight, good corrosion resistance, castability and excellent thermal properties these composites are gaining wide popularity as high performance material. Aluminum based hybrid composites shows improved primary and secondary properties over conventional base alloy [2, 3]. Ceramic materials generally used to tailor the desirable properties of Al alloys are SiC, TiC, TiB<sub>2</sub>, ZrB<sub>2</sub>, AlN, Si<sub>3</sub>N<sub>4</sub>, Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub>. These ceramic materials are with high strength and high hardness. However, it displays brittle behavior and has low resistance to fracture which can be improved by modifying the reinforcement grain size, shape and by incorporating additional phases [4].

It has been widely reported that directional solidification during cooling of the casting improves the grain structure of the samples and helps to improve the properties of the composite. Aluminum based HMMCs are widely gaining interest in the tribological field because of its excellent strength to weight ratio. Particulate reinforced hybrid composites exhibit excellent isotropic properties [5]. Stirring action in the casting process will evenly distribute garnet particles on the composite matrix. Various parameters such as pouring temperature, rotation speed which affect fabrication sound casting have been investigated extensively to optimize the parameters. Joel Hemanth[6] studied the parameters which affect the solidification of aluminium alloy.

Experiments were carried out on a mold having high cooling rates to show range of solidification temperatures which are influenced by variation of cooling rates. Many researchers have exploited the various types of artificial reinforcements in aluminum alloy matrices such as SiC, SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, BN, B<sub>4</sub>C, WC, TiC etc to achieve demands of various applications [7,8]. The investigation carried out by A. Saravanakumar[9] begins with fabrication of Al 6063/Al<sub>2</sub>O<sub>3</sub>/Gr hybrid composites using liquid metallurgy technique, followed by the wear study using conventional tribometer apparatus for different parameters like sliding speed, applied loads and a discussion of effect of reinforcements. The wear resistance is proportional to dispersoid content. At higher loads, the wear mechanism changes to delamination.

The carbon being soft, grease and ability to withstand very high temperature makes the alloy very high wear resistant and self-lubricating material by forming a tribolayer between the contact surfaces [10]. Microstructural studies have revealed uniform distribution of carbon in the matrix with improves wear behavior. But with increasing carbon content, leads to weakening of matrix and increases wear rate. Hence 3wt% of carbon is considered as secondary reinforcement in the current work [11,12]. M Uthayakumar studied the influence of graphite on hardness wear property of Al6061 hybrid composite with Al<sub>2</sub>O<sub>3</sub> and SiC particulate. It was discovered that addition of Graphite particles decreases the microhardness but immensely improves wear resistance of the samples [13]. In recent years many researchers have worked on the combination of graphite with SiC and Al<sub>2</sub>O<sub>3</sub> and found the similar results. Joel Hemanth [14] investigated effect of chills on wear behavior. M Babic reinforced 1wt% Grand 10wt%SiC with A356 to investigate the tribological properties. The MML formed by the graphite reduces the wear drastically [15]. Rapid and directional solidification is one of largely accepted method to obtain finer microstructure and improved properties which can be achieved by the application of chills. Although the sand cast composite results in some defects like porosity, the application of chills will improve the directional solidification to achieve finer microstructure with improved tribological properties.

## EXPERIMENTAL MATERIAL AND METHOD

### Experimental Material

Commercially available and generally known piston alloy (LM 13), multicomponent Al-Si-Ni-Cu-Mg alloy with lower concentrations of Fe and Mn was used in the present investigation. LM 13 Aluminum alloy matrix exhibits excellent casting properties with reasonable strength. Aluminum has low melting point and high ability to hold the reinforcement. It is suitable for automotive application with its excellent thermo-physical properties. In the present study low cost and naturally available hard ceramic garnets are reinforced in the proportion of 3wt% to 12wt% in steps of 3wt%. Based on the literature it was found that various researchers have concluded 3wt% range of carbon gives the optimum properties. Hence in the present study constant 3wt% carbon is incorporated while developing the hybrid composites. Metallic and non-metallic chills of dimension 25mmx35mmx170mm were used to investigate the effect of directional solidification on mechanical properties of the composite. The effect is compared with composites developed without using chills.

### Experimental Method

#### Fabrication of the Composite

Light weight and low cost production is the primary factor for wider application of HMMCs in modern industry which can be achieved by cheaper reinforcements, simpler fabrication methods, and higher production volume. One of the low cost fabrication process stir casting method is used to develop the composites with better bonding of metal matrix with reinforcement particles. Stir casting method is well known for uniform distribution of the reinforcements because of stirring action and flexible for different low melting temperature materials. In the present study Aluminum alloy is melted

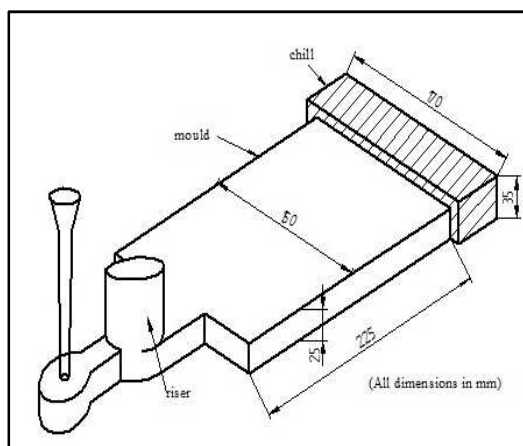
in a resistance furnace at around 750°C. Garnet and carbon particulates were preheated to add in the molten matrix reinforced and poured in the sand mold with different chills such as copper, steel, iron and silicon carbide. One mold without the chill also prepared to compare the results. Table 1 show the thermal-physical properties of chill materials. Figure 1 show position of the chill in the mold. Specimen is prepared from chill end of the composite to investigate dry sliding and abrasion behavior.

**Table 1: Thermo-Physical Properties of Chill Materials**

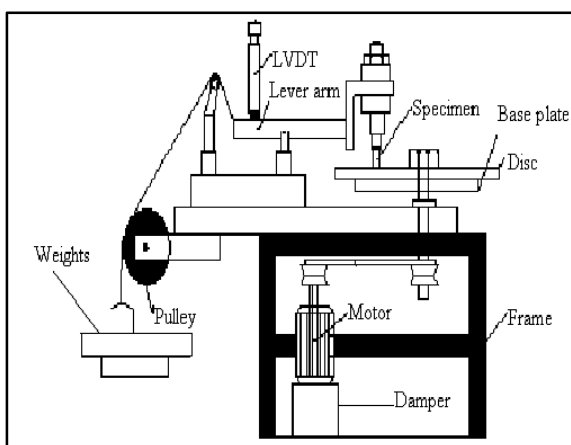
Material of Chill Block	Density kg/m <sup>3</sup>	Specific Heat J/kgK	Thermal Conductivity
Copper	8.96	0.448	1.022
Steel	7.85	0.421	0.109
Cast iron	7.61	0.401	0.160
Silicon carbide	2.36	1.095	0.039

### Wear Test

Specimens of 8mm diameter and 30mm length were cut from the chill end of the composite. Dry sliding wear behavior of the samples were studied using a pin-on-disc wear testing machine (Figure 2) as per ASTM G-99-95. All the tests were performed on hybrid composite pins at different loads 10 to 50 N in steps of 10N for a sliding distance of 1500m. For each test, the pin was cleaned with acetone and weighed accurately using digital electronic balance of accuracy 0.1mg. Each test was repeated for 3 times, and the average results were taken.



**Figure 1: Chill Casting Setup**



**Figure 2: Pin-On-Disc Test Setup**

### Abrasion Test

The three body abrasion test has been carried out at room temperature on the specimen using standard rubber wheel abrasion testing apparatus as per ASTM G65 standard. Table 2 details the sand abrasion tester employed in the present study. Loads are varied from 1 kg to 5 kg at different wheel speed and silica sand of grain size 50µm has been used as the abrasive media. The abrasive has been fed at the contacting face between the rotating rubber wheel and the test sample. The tests were conducted at a rotational speed of 100, 150, 200 rpm. The rate of feeding the abrasive was 350 g/min. The sample has been cleaned with acetone and then dried. Its initial weight has been determined in a high precision digital balance, before it has been mounted in the sample holder. Figure 3 show sand abrasion testing setup with specimen.

**Table 2: Particulars of the Sand Abrasion Testing Machine**

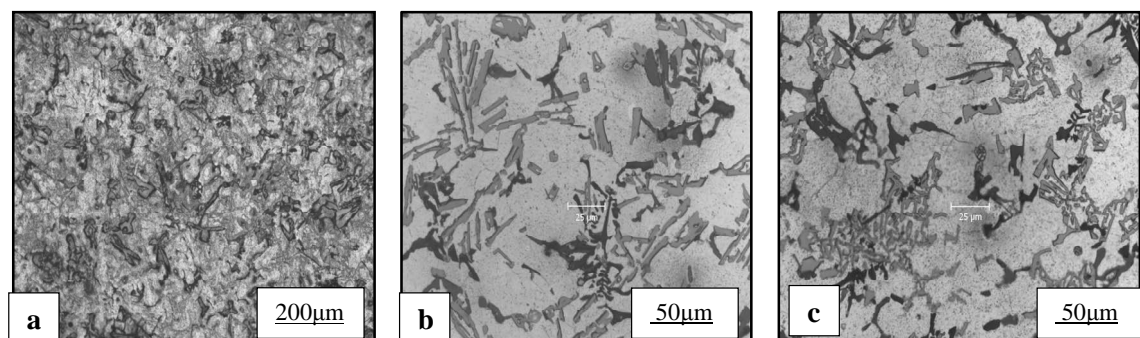
S.No.	Description	Particulars
1.	Abrasive material	AFS 50/70 Quartz grain sand
2.	Abrasive flow rate	0.35 kg/min
4.	Rubber wheel material	Chlorobutyl rubber
5.	Rubber wheel diameter	228.6 mm
6.	Rubber wheel hardness	A-60, A-70-72
7.	Rubber wheel speed	250 rpm
8.	Specimen dimension	(76 × 25.4 × 12.7)mm
9.	Load	Min - 1kg, Max - 5kg

**Figure 3: Sand Abrasion Testing Setup with Specimen**

## RESULTS AND DISCUSSIONS

### Microstructure and Mechanical Behavior

Figure 4 shows the optical micrograph of microstructure of the samples. It shows the uniform distribution of the reinforcements and good bonding between reinforcement and matrix. Although in situ process is known for better bonding between matrix and reinforcements it is not developed for mass production. However stir casting method is simple and convenient which is used by many researchers for successful fabrication of the composite. Copper chill cast samples shows the finer microstructure.

**Figure 4: Microstructure of Chill Cast HMMC**

### Wear Behavior

The influence of the weight fraction of garnet on the weight loss of hybrid composites is shown in Figure 5. It shows the lesser weight loss for the samples consisting 9wt% garnet with copper chill. It can be seen that, wear resistance

of the samples reduces for steel, iron and silicon carbide chills in that order and it is least for samples without chills. For higher values of reinforcements (12wt%) wear resistance decreases for all chill material samples. It is also found that weight loss was decreased with increasing weight percentage of the reinforcement's up to 9wt% of garnet due to the fact that garnet particles prevent the movement of dislocation and act as the obstacles wear. Figure 6 shows the SEM of worn surfaces of 9wt% garnet samples using copper and without chill. Copper chill cast samples offers more resistance to dry sliding wear.

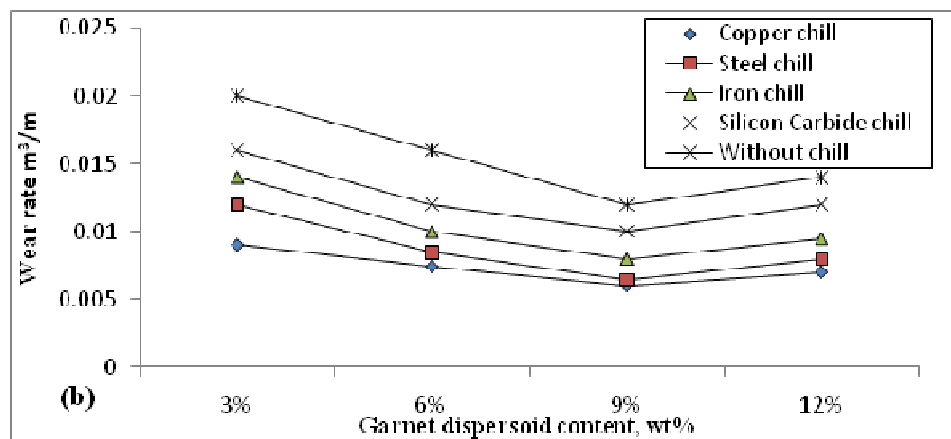


Figure 5: Wear Rate of Composite Vs wt% of Garnet

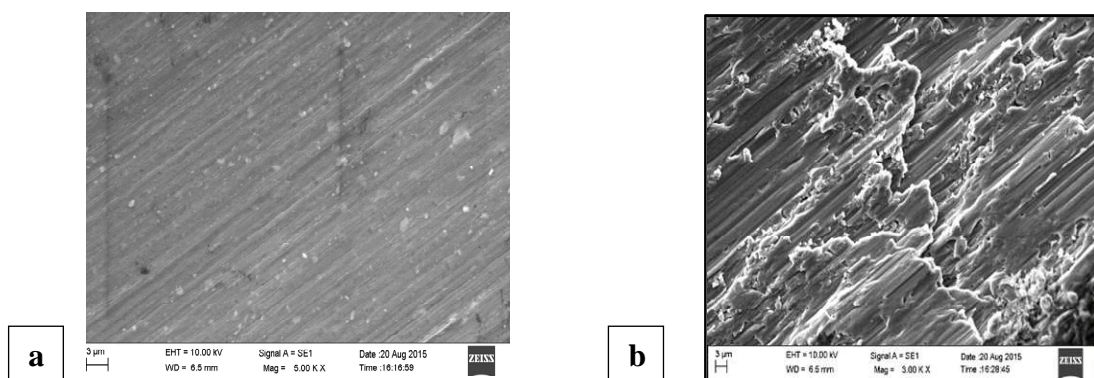
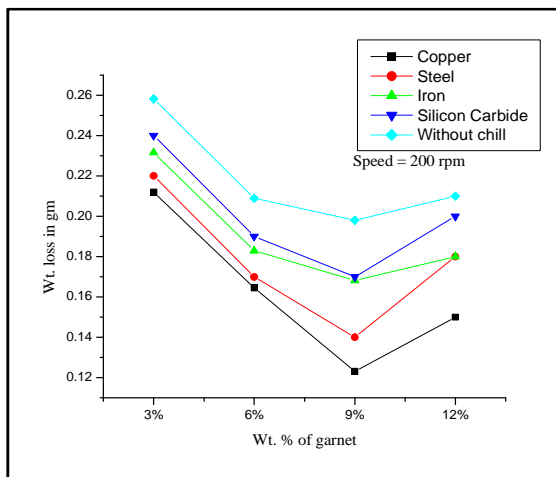


Figure 6: SEM of Al+9wt% Garnet+3wt% C composites using (a) Copper Chill (b) Without Chill

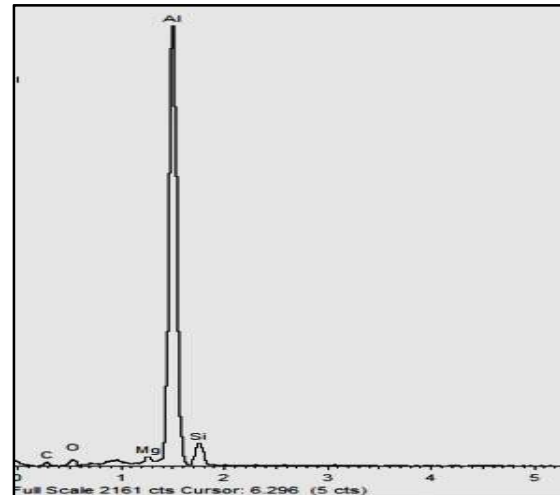
### Abrasion Behavior

Weight loss due to three body sand abrasion of the composites is shown in figure 7. Wear rate gradually decreases up to 9wt% of garnet and for higher percentage of reinforcements dislocation of the reinforcements takes place which increases the wear rate for 12wt% of garnet. Out of all the chills and without chill sample, copper chill cast samples show lower wear rate because of its higher volumetric heat capacity. An increase in cooling rate (using a copper chill) induces finer intermetallic particles than those that form when applying a lower cooling rate (when using iron, stainless steel, non-metallic chill). Because the formation of intermetallics is a diffusion- controlled process relating to the rejection of atoms of elements into the front of the solidifying interface, increasing the cooling rate will delay the formation of these compounds. Figure 7 shows the EDX image of worn surface of aluminum hybrid composite with 9wt% garnet and 3wt% carbon. It shows the various composition of the sample and the presence of O in the image proves the formation of tribolayer between the contacting surfaces.

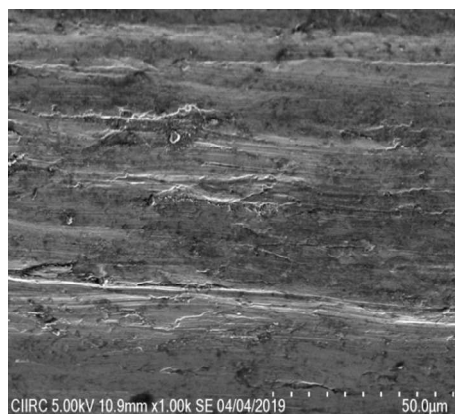




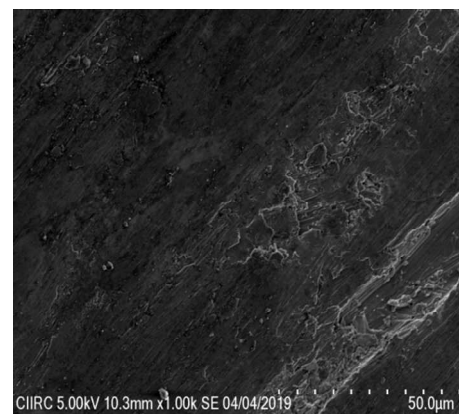
**Figure 7: Weight Loss v/s % of Garnet for Abrasion Test**



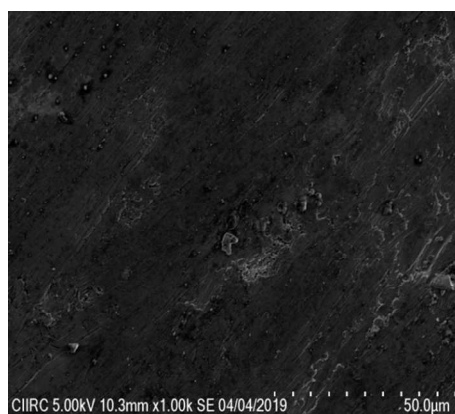
**Figure 8: EDS of the Specimen**



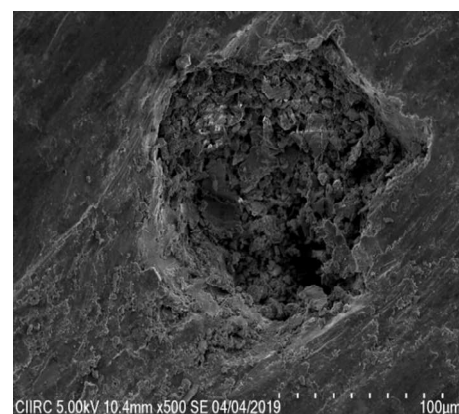
(a)



(b)



(c)



(d)

**Figure 9: SEM of Worn Surfaces of Al + 9wt% Garnet + 3wt% C Composites using (a) Copper (b) Steel (c) Silicon Carbide Chill and (d) Without Chill**

Figure 9 shows the SEM of sand abrasion surfaces of 9wt% garnet for different chill materials. Higher wear resistance is observed for chill cast samples in the order of copper, steel, silicon carbide. Results are compared with samples without chill materials. It shows higher weight loss of the material. The garnet hard ceramic particles act as the obstacles to the movement of dislocation. The garnet particles in the matrix alloy provide protection to the softer matrix. Thus, limiting the deformation and also resists the penetration and cutting of slides on the surface of the composites. It was

previously reported in the literature that the hard ceramic particles in the Al matrix materials could enhance the wear resistance of these materials drastically. This result is a good agreement with the result of many researchers. Increase in cooling rate (using a copper chill) induces finer intermetallic particles than those that form when applying a lower cooling rate (when using iron, stainless steel, non-metallic chill). Because the formation of intermetallics is a diffusion-controlled process relating to the rejection of atoms of elements into the front of the solidifying interface, increasing the cooling rate will delay the formation of these compounds.

## CONCLUSIONS

- LM 13 Aluminum alloy matrix garnet-carbon reinforced composites were successfully developed by stir casting route using different end chill materials.
- Microstructural studies indicate uniform distribution of the dispersoids and good bonding of the particles with the matrix. Copper chill cast samples with 9wt% garnet shows the finer and equiaxed microstructure.
- Samples cast using copper chill block shows the significant improvement in tribological properties.
- Thermo-physical property of chills attributes the improvement in the behavior of the composite.

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